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FIFTH BIMONTHLY REPORT ON THE RT-21

TRANSMITTER DEVELOPMENT

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Table of Contents

I. Purpose

See Bimonthly Report - No. 1.

II. Abstract

During the present reporting period, a visit from the customer resulted in several significant decisions concerning the planning of the remainder of this program. At the time of the visit four transistors were delivered by the customer for evaluation to determine their suitability as output transistors for the transmitter. In that these units represent what appears to be the best transistors which are presently available in the high frequency, high-power field it was agreed that work should not be held up any longer and the transmitter should be designed for whatever power output level can be obtained using these or comparable transistors. It appears that it is reasonable to expect an output of about 1 watt at 30 mc. with these units rather than the 10 watts originally desired. Since the design of many parts of the transmitter hinge upon the type of output transistor used, it was agreed that if an improved transistor should become available before the completion of the present program, it would not be incorporated in the design unless to do so would not require any appreciable redesign.

3 Mc - 1.8 watts
30 Mc - 400 mw.

It was further agreed that the original temperature specifications which called for operation up to 50°C should be revised. The reason for this revision is again due to output transistor limitations. If operation at 50°C was required it would be necessary to derate the output power still further. On the other hand 50°C represents quite a modest temperature as far as the other components are concerned and would not call for any special

precautions. With a suitable output transistor, there would be no changes required in the design of the transmitter for operation at room temperature or 50°C.

A design, as reported previously, has been worked out for a three variable pi antenna matching network. The values of the variable components are realizable but not readily available. In order to construct the antenna matching network in a small physical volume it would be necessary to initiate a special miniature variable capacitor development. This would be time consuming (6 months has been quoted by one capacitor manufacturer and it is presumed that this time could not be improved upon materially by having the work done with [redacted] facilities). It was consequently 25X1
agreed that since the three variable pi system solved, in principle, the problem of matching to the complete impedance rectangle originally requested, for the present transmitter it would be satisfactory if the modified impedance area was matched. To match to the modified area, drawn in Figure 9 of the Fourth Bimonthly Report, a two variable network is required. The values of the variable reactances are such that the capacitor can be constructed in miniaturized form by modifying an existing capacitor. The time and expense of a separate capacitor development are consequently saved.

During the course of the visit, the physical size of the complete transmitter was discussed. The present program calls for delivery of an operative electrical model using miniaturized components. While the components will not be mounted so as to achieve maximum density it is anticipated that a reasonably small overall volume will be achieved. No effort is being made on the present phases of the program to achieve maximum component density for two reasons. The first is that to do so constitutes a major phase of the overall program in itself (Phase C in the original Proposal) and secondly, a piece of equipment so constructed makes testing, evaluation and modifications of any sort, virtually impossible. At the present time it is estimated that the package to be delivered at the conclusion of Phase B of this program will not exceed 12" x 6" x 3". Note. approx 8x6x3. This is not firm yet. DR.

Work has been slowed down during the past reporting period awaiting the arrival of suitable transistors for the output stage. Although there are still a large number of sections of the transmitter which have not been designed, progress could not be made until the characteristics of the output transistor were known. However, a number of matters were investigated. A description is given in this report of a considerable simplification which was achieved in the design of the bandswitching circuitry. The number of transistors required has been reduced from 34 to 15. *this has been reduced again. A short investigation has also been carried out to determine the upper power level at which the transistor switches, used to move the taps on the tank coils, will operate satisfactorily. This report also includes a short account of the antenna matching servo system which has been constructed.

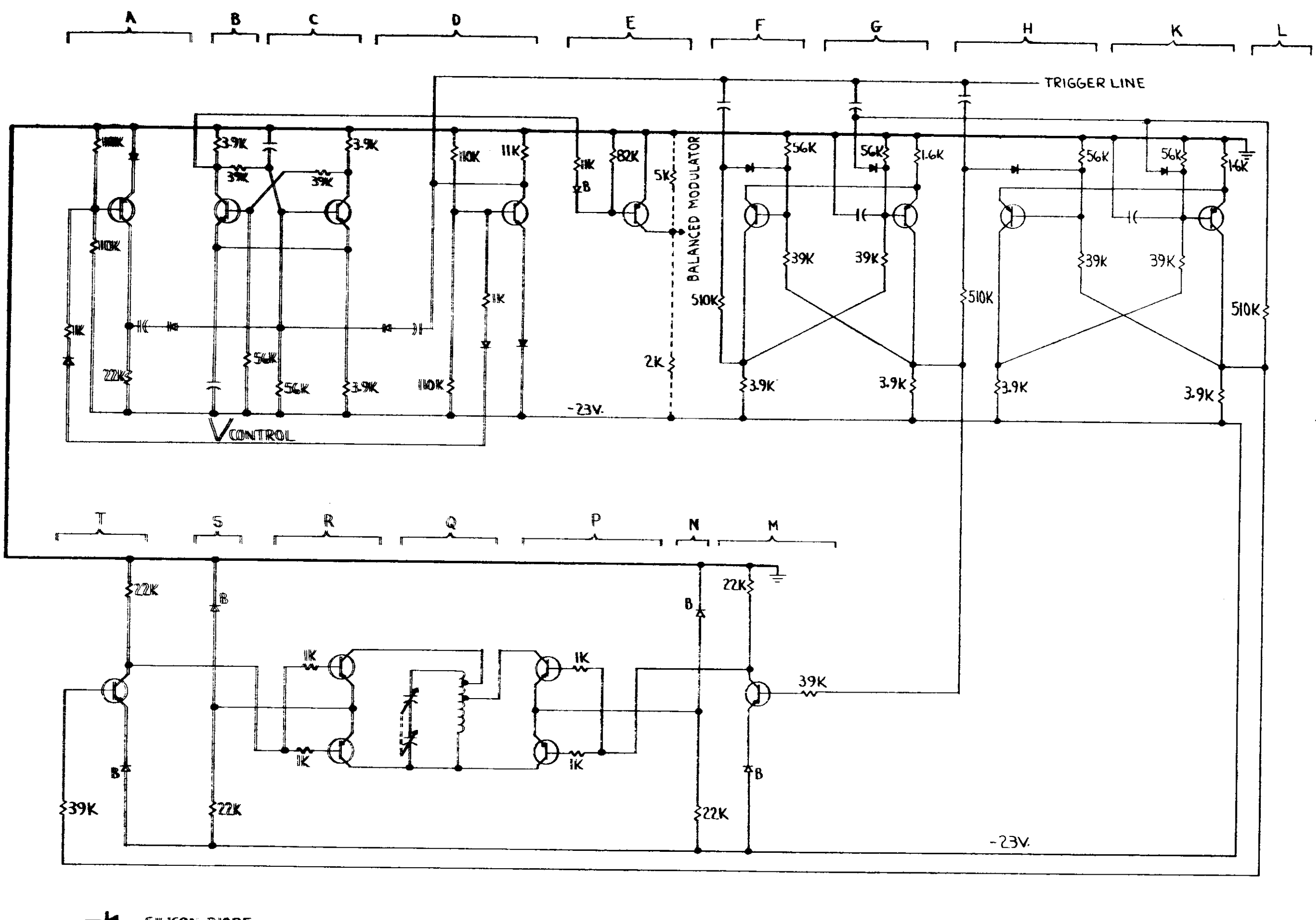
III. Factual Data

1. Automatic Transmitter Tuning

(i) Introduction

The system to be described performs the same operations as the system described in the Fourth Bimonthly Report, pages 18-25. However, it uses few components as a diode gating technique is used where possible.

The principle of diode gating is readily understood by inspection of block F of Figure 1. A diode gate consists of a capacitor, one side of which is connected to the trigger voltage, the other side being connected to a diode and a resistor. Via the resistor, the side of the capacitor away from the trigger line is raised in voltage until there is no voltage drop across the resistor, the anode side of the diode is raised to the same voltage, as the diode is reverse biased. The speed of the voltage rise depends largely upon the time constant of the capacitor and the resistor. If the trigger voltage rises suddenly (compared to the time constant), the voltage of both sides of the capacitor and the anode voltage will rise by the same amount. If the anode voltage exceeds the cathode voltage by more than the forward drop across the diode, a current pulse will pass through the diode, the pulse being large enough to turn a transistor on or off. A positive voltage pulse can thus create a positive current pulse if the diode is connected as shown and the anode voltage was sufficiently high before the pulse was applied. If the diode is reversed, a negative voltage pulse will create a negative current pulse in a similar manner. When the DC voltage (-23 V) is applied to the system, it is of importance that each of the flip-flops: blocks B and C, F and G and H and K, be in its appropriate state. This is ensured by means of a small capacitor connected from ground to the base of one of the two flip-flop-transistors. In this way the C-transistor is kept turned on, and the G- and the K-transistors are kept turned off during the initial transients.



—▶|— SILICON DIODE
—▷|— GERMANIUM DIODE
—▶|B— BREAKDOWN DIODE (8 VOLTS)

FIGURE-1 SIMPLIFIED ELECTRICAL BANDSWITCHING CIRCUITRY

(ii) Cycling

When $V_{control}$ has increased from -23 Volts to 0 Volts the A transistor is turned off. This causes a sudden drop in the voltage across the 22 KΩ resistor in block A. This negative pulse is transmitted via the capacitor and diode to the base of the C-transistor. The pulse is large enough to turn the C-transistor off. Consequently the B-C flip-flop will change its state so that the B-transistor conducts. The voltage drop across the 3.9 KΩ resistor in block B changes from less than 8 Volts to more than 8 Volts and the E-transistor starts to conduct. The voltage of the connection from block E to the balanced modulator is changed from -16 V to 0 Volt. As a result $V_{control}$ resets to -23 Volts.

The D-transistor is then turned off and the voltage drop across the 11 KΩ resistor in block D decreases abruptly. This positive pulse is large enough to raise momentarily the base voltage of the C-transistor above its emitter voltage. The C-transistor is turned on, and the B-C flip-flop reverses its state. The C-block is again the conducting side and the B-transistor remains turned off. The voltage of the connection from block E to the balanced modulator changes back (from 0 Volt) to -16 Volts and $V_{control}$ rises (from -23 V) to 0 Volt, making the cycle of $V_{control}$ start over again.

In both cases the triggering takes place via a capacitor in series with a diode. During the triggering the charge on the capacitor will change, and the resultant charge has to leak away before the cycle is repeated. As the cycle lasts about one second, the excess charge will leak through the back resistance of the diode.

(iii) Tank Circuit Switching

The first time $V_{control}$ rises from -23 V to 0 Volt, the F and H sides of the FG- and the HK-flip-flops were conducting because the G- and the K-transistors were turned off when power was applied.

The only signal used to control the tank circuit is the positive pulse to the trigger line generated by the D-transistor, at the time when it is turned off. The pulse is used exclusively to turn transistors off. The pulse indicates that $V_{control}$ has reset to -23 Volts. When power is applied to the system $V_{control}$ is at -23 Volts. Whatever pulses are generated at that time do not effect the G- and K-transistors, since they are turned off during the charging time of the capacitor connected to the base.

It takes about one second for $V_{control}$ to increase from -23 V to 0 Volt. During that time, via the 510 KΩ resistors,

(a_1) F-capacitor charges to the collector voltage of the F-transistor on the side away from the trigger line. This voltage is less than 0.5 Volts from the base voltage of the F-transistor as this transistor is conducting. However, the F-diode does not bypass the F-transistor, as the forward drop across the diode is 0.5 Volts.

(b_1) H-capacitor charges to the collector voltage of the G-transistor on the side away from the trigger line.

This voltage is considerably lower than the base voltage of the H-transistor as the G-transistor is turned off. The direction of the H-diode prevents any current from flowing.

(c_1) G-capacitor charges to the collector voltage of the K-transistor on the side away from the trigger line. This voltage is considerably lower than the base voltages of the G- and K-transistors, both of which are turned off. The direction of the G- and K-diodes prevents any current from flowing.

When $V_{control}$ has reset and a positive pulse appears on the trigger line, the following will occur simultaneously:

(a_2) The voltage rise across the F-diode is large enough to raise the base voltage of the F-transistor above its emitter-voltage. The F-transistor is turned off, and the G-transistor is turned on.

(b_2) The reverse voltage drop across the H-diode is larger than the positive pulse so that no current will pass through the H-diode. The H-transistor remains conducting.

(c_2) The reverse voltage drop across the K- and G-diodes is larger than the pulse so that no current will pass through the diodes. (Even if a pulse was large enough to overcome the voltage drop across the diode, it would only tend to turn the K- and G-transistor off even harder.) The K- and G-transistors remain turned off, though the G-transistor is turned on a little later as indicated in (a_2) above.

The first pulse, consequently, produces no change in the state of the HK flip-flop but changes the state of the FG flip-flop so that the G-transistor is conducting. This change causes three subsequent events:

(a_3) The voltage across the F-capacitor will fall as the voltage drop across the 3.9 KΩ resistor in the F-block falls.

(b_3) The voltage across the H-capacitor will increase as the voltage drop across the 3.9 KΩ resistor in the G-block is increased. It is assumed that the FG and HK flip-flops are essentially identical, so that the voltage swing across the 3.9 KΩ resistors in any of the four blocks is the same when the transistors of the block are turned on and off. (The base currents to the M- and T-transistors are small compared to the currents through the G- and K-transistors when they are conducting.) The collector voltage of the G-transistor is therefore approximately the same as the base voltage of the H-transistor.

As the forward drop across the H-diode is 0.5 Volt, there is a sufficient margin to take care of differences between the G- and the H-blocks. No current will flow to the H-transistor base until the second pulse appears on the trigger line.

(c_3) The change in voltage across the 3.9 KΩ resistor in block G from less than 8 Volts to more than 8 Volts turns on the M-transistor. (The emitter of the M-transistor is connected to the -23 Volt line via an 8-Volt breakdown diode.) The two P-transistors will saturate with base currents, given by $23 - 2 \times 8 = 7$ Volts divided by 1 KΩ + the base resistance. Thus half of the coil in block Q, has been short-circuited via the two P-transistors, meaning that the second time $V_{control}$ rises from -23 to 0 Volt, in block Q, only half of the coil will be effectively in parallel with the capacitor.

The two P-transistors constitute a switch. The operation of the switch has been checked at power levels as high as 2 Watts, in "closed" and "open" position. The performance of the switch compares well with that of a short-circuiting wire used for comparison.

The second time a pulse is applied to the trigger line, the following will occur simultaneously (remembering that only positive pulses can turn the transistors off):

(a_4) The F-transistor is already turned off and therefore is not affected by the pulse.

(b_4) The H-transistor which was conducting is now turned off (see (b_3)) and the HK-flip-flop changes state.

(c_4) The voltage on the side away from the trigger line of the G-capacitor was insufficient for the pulse to turn the G-transistor off. The K-transistor was already turned off.

The second pulse thus does not change the state of the FG-flip-flop (G is still the conducting side) but makes K the conducting side of the HK-flip-flop. This change causes the following to occur:

(a_5) The side away from the trigger line of the G-capacitor is charged to a higher value as the voltage drop across the 3.9 KΩ resistor in the K-block is increased.

(b_5) The same voltage increase will turn the T-transistor on, which in turn saturates the two R-transistors. As they short-circuit three-quarters of the Q-coil only one-quarter will be active when, for the third time, $V_{control}$ rises from -23 to 0 Volts. When $V_{control}$ resets from 0 to -23 Volts a third pulse on the trigger line results in the following state of affairs:

(a_6) The F-transistor is already turned off and therefore remains turned off.

(b_6) The H-transistor is already turned off and therefore remains turned off.

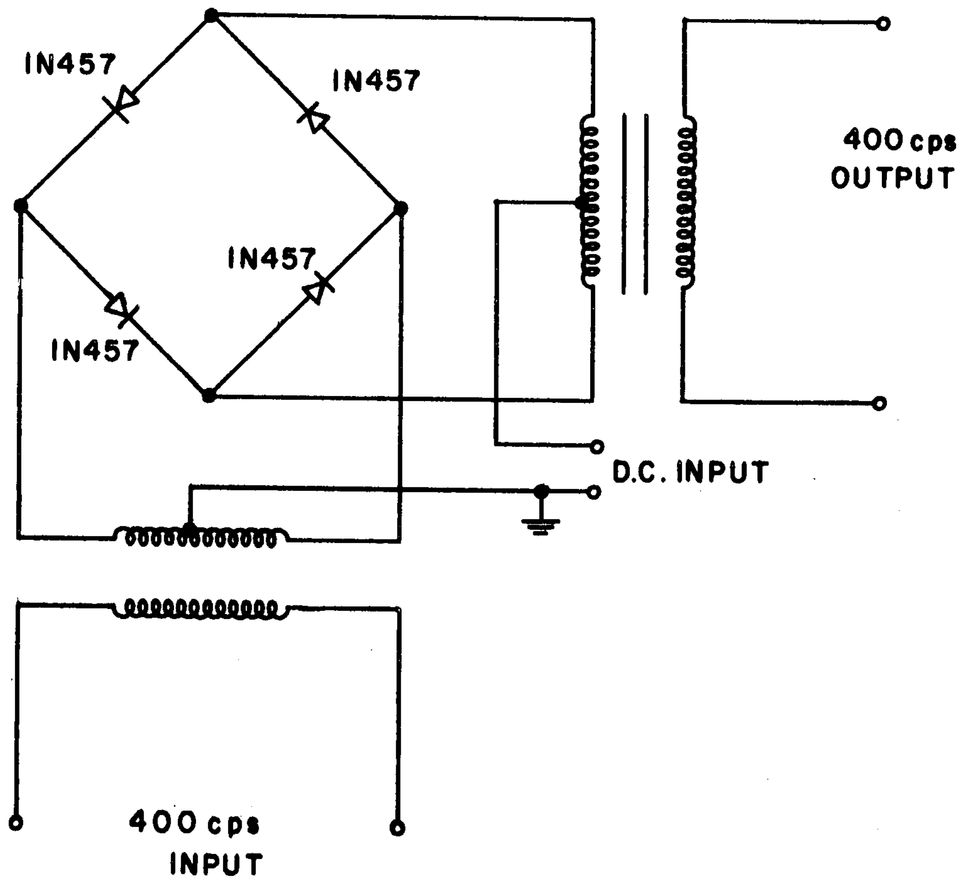
(c_6) The pulse will turn the G- and K-transistors off (see (a_5)) thereby resetting the FG- and the HK-flip-flops to their initial states with the F- and H-sides conducting. This change turns off the M- and T-transistors. The transistor-switches in block P and block R will open (all 4 transistors turn off). A complete reset to the initial state of the band switch is achieved so that when $V_{control}$ rises for the fourth time from -23 V to 0 Volt, the coil in block Q will present its full inductance and the lowest range of frequencies will be scanned.

2. Impedance Matching Servo System

Since the output characteristics of the RF power transistor remained unknown during the last period, further work involving the variable elements in the matching network was postponed. However, work has proceeded on other aspects of the servo system. The servo system will utilize the output of the impedance detectors (described in the Third Bimonthly Report) to operate two-phase 400 cycle servo motors which in turn drive the elements in the impedance matching network. Since the impedance detectors provide DC output signals, these signals must be converted to 400 cycle signals capable of driving a servo motor. The DC to AC conversion is accomplished by means of a ring modulator (shown in Figure 2). This circuit, described by Moody(1), provides an AC output whose phase is determined by the polarity of the DC input. Miniature transformers (UTC DO-T24) having a 5/16" diameter and 13/32" length are used in the ring modulator. Power amplification is achieved by connecting the output of the ring modulator to a Norden-Ketay servo amplifier, type TSA4-200A. This servo amplifier then drives a Norden-Ketay servo motor, type 008E2C. The servo amplifier and motor have a combined volume of approximately 3 cubic inches.

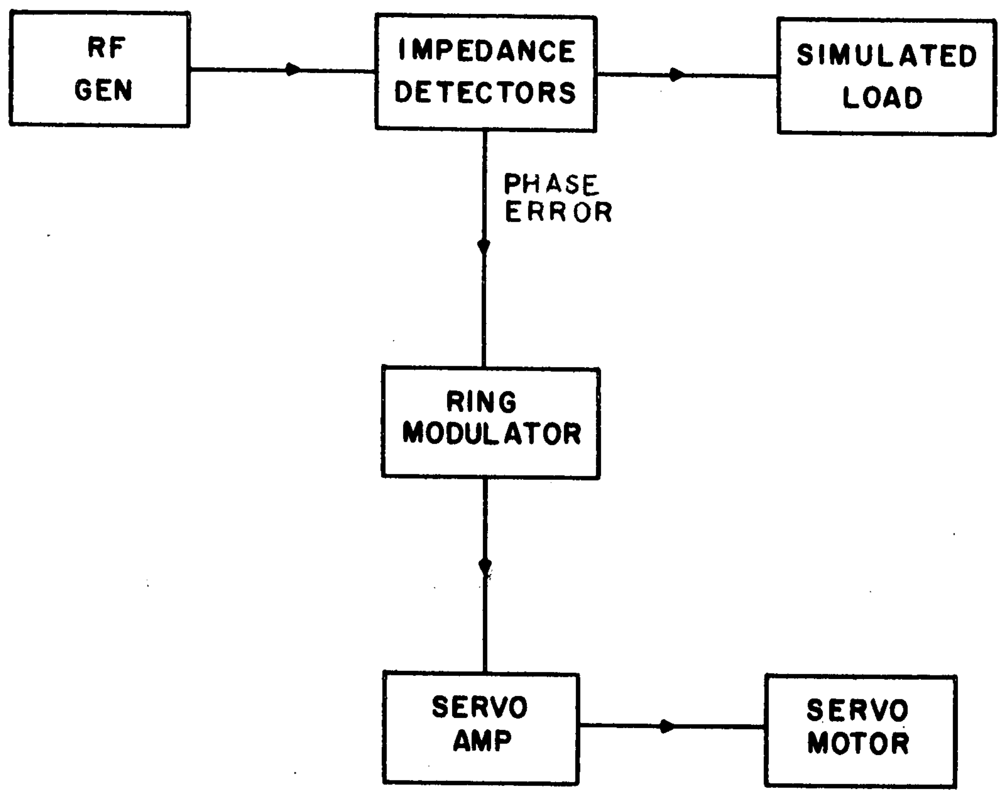
An open loop servo system (see Figure 3) has been constructed to observe the sensitivity of the unloaded servo motor to the output signal from the impedance phase detector. (It is anticipated that the impedance phase signal will be weaker than the impedance magnitude signal.) With a 3 Watt RF generator driving a simulated load impedance, it appears that a negligible impedance phase angle can be achieved.

A further evaluation of the servo operation requires more precise information regarding the output characteristics of the RF power transistor and the design of the variable elements in the impedance matching network. It was originally anticipated that the impedance detectors would be used in conjunction with a 10 Watt output stage. However, since it now appears that the power output may be an order of magnitude lower, it may be necessary to insert additional amplification between the ring modulator and the servo motor.



RING MODULATOR

FIGURE 2



OPEN LOOP UNLOADED SERVO CIRCUIT

FIGURE 3

IV. Conclusions

The simplified band switching circuitry has been constructed and operated successfully. The reduction in circuit complexity from 36 to 15 transistors with their associated components, constitutes an appreciable step in the direction of ultimate miniaturization. Furthermore the transistor band switches have been shown to be satisfactory for switching RF power at levels as high as 2 Watts. This is significant in that it may prove desirable to switch the interstage coupling network between the driver and output stages.

A low level crystal oscillator that can be tuned with voltage variable capacitors from 3 to 30 mc. has been built. It is anticipated that this oscillator will drive a broadband buffer amplifier which will, in turn, drive the special power transistors supplied by the customer. The exact input and output characteristics have not been determined to date. However, preliminary experiments indicate that an output power of approximately 1 Watt can be obtained in an untuned amplifier with a DC efficiency of 22%. Experimental circuits are being constructed to explore more fully the potentialities of these transistors.

The antenna impedance matching servo system has been built in open ended form. It was not possible to close the loop because the required elements for the matching network were and are still not known. Further work in this area is largely dependent upon establishing the output impedance level required by the output transistors. As far as open loop tests can check the operation of the system, performance appears to be satisfactory.

Specifications have been forward. DR

V. Future Plans

As soon as a fuller set of specifications is obtained for the power transistors which have been delivered, it will be possible to proceed with the design of the antenna matching network. Knowing the output impedance of the final amplifier, it will be possible to specify the maximum and minimum values for the variable reactances. Fabrication of the components can then commence. Similarly, when the power output level is known, the gain necessary in the antenna servo loop can be determined and appropriate modifications made.

When the gain and output level of the final stage have been determined the design of the driver stages can be completed. At the present time, the electrically tuned oscillator followed by broadbanded stages appears to be the most desirable approach. Bandpass 3-15 MC & 15-30 MC.

Construction of several blocks of the transmitter will be started in an advanced breadboard form so that the overall operation of the transmitter can be checked before final construction is undertaken. This is necessary, particularly in the RF portion of the equipment, where physical layout is of significance.

VI. Bibliography

1. N. F. Moody, "A Silicon Junction Diode Modulator of 10^{-8} Amp. Sensitivity", Proc. of the Nat. Elec. Conf. 1955, Vol. 11, p. 441.

VII. Identification of Key Technical Personnel

The following biography should be added to those appearing in previous bimonthly reports.

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